Thunder Bay North Harbour

March 2006

Report # MOE-02-006

SEDIMENT AREA AND VOLUME ESTIMATES BASED ON TOXICITY, BIOMAGNIFICATION, AND MERCURY CONCENTRATIONS: THUNDER BAY NORTH HARBOUR

THUNDER BAY NORTH HARBOUR

Area Of Concern
Report # MOE-002-06

SEDIMENT AREA AND VOLUME ESTIMATES BASED ON TOXICITY, BIOMAGNIFICATION, AND MERCURY CONCENTRATIONS: THUNDER BAY NORTH HARBOUR

Draft Report Prepared for the Ontario Ministry of the Environment

by

North/South Consultants Inc.

March 2006

North/South Consultants Inc.
83 Scurfield Blvd.
Winnipeg, MB R3Y 1G4
Tel: (204) 284-3366 Fax: (204) 477-4173
Email: nscons@nscons.ca

North/South Consultants Inc.
Aquatic Environment Specialists

LIST OF ABBREVIATIONS AND ACRONYMS

AOC	Area of Concern
d.w.	dry weight
EC	Environment Canada
Hg	Mercury
IJC	International Joint Commission
MOE	Ministry of the Environment
NSC	North/South Consultants
NWRI	National Water Research Institute
PSQG	Provincial sediment quality guideline
RAP	Remedial Action Plan
RFP	Request for proposal
SEL	Severe effect level
UTM	Universal Transmercators

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Page

1.0 INTRODUCTION

As a result of the Great Lakes Water Quality Agreement of 1978, the International Joint Commission (IJC), along with participating federal, state, and provincial agencies, identified the Thunder Bay Harbour (Figure 1) as one of 43 degraded areas on the Great Lakes. These 43 "Areas of Concern" (AOC), were identified as locations for which cleanup or Remedial Actions Plans (RAPs) would be required. Since that time, two RAP reports have been produced for the Thunder Bay Harbour AOC: "Stage 1: Environmental Conditions and Problem Definition" (Thunder Bay RAP Team 1991) and "Stage 2: Remedial Strategies for Ecosystem Restoration" (Thunder Bay RAP Team 2004). The Stage 1 RAP report provided a detailed description of the 'environmental problems' in the Thunder Bay AOC. The Stage 2 RAP report outlined the various strategies for remediation of the Thunder Bay AOC (Thunder Bay RAP Team 2004). A Stage 3 RAP report will be prepared later in the process. The ultimate goal is to restore the beneficial uses of aquatic ecosystems.

One of the primary issues identified for the Thunder Bay AOC is mercury (Hg) contamination of sediments in the northern portion of Thunder Bay Harbour, in the area adjacent to the Cascades Fine Papers Thunder Bay Inc. ("Cascades") (Thunder Bay RAP Team 2004). The Thunder Bay Harbour RAP Stage 2 Report (2004) recommended that the contaminated area in the northern section of the harbour be better defined by conducting additional sediment assessments, and that a sediment management plan be developed to address this sediment contamination. Although various studies have been conducted in the area, the Ontario Ministry of the Environment (MOE) identified the need for additional data to address information gaps and to better delineate the extent of contamination in the northern section of the harbour (areal and volume sediment estimates) and to integrate the findings of all relevant past studies in the area. To address these information gaps, the Ontario MOE issued a Request for Proposal (RFP) entitled: "Collection, Handling, Analysis and Reporting of Sediment Samples from the Thunder Bay Harbour Area of Concern." North/South Consultants Inc. (NSC) was retained to conduct a sediment survey designed to:

- Measure concentrations of total mercury (and supporting variables) in sediment cores collected from defined sites (universal transmercator [UTM] coordinates were provided by the Ontario MOE) in the northern portion of Thunder Bay Harbour (i.e., the "Study Area"); and,
- Generate estimates of the volume and area of organic/fibre materials in the sediments within the northern portion of Thunder Bay Harbour adjacent to the Cascades facility.

Several studies have been conducted in the area over several decades, defining the concentrations of mercury in surficial and deeper sediments, as follows:

- 2005 surficial sediment survey (NSC and Quester Tangent 2006);

- 2005 surficial sediment survey (Milani and Grapentine In Prep.);
- 2003 and 2004 surficial sediment survey (Fletcher In Prep.);
- 2002 surficial sediment survey (Milani and Grapentine 2005);
- 2000 surficial sediment survey (Jaagumagi 2001);
- 1999 surficial sediment survey (Richman 2004);
- 1997 sediment core survey (Stantec 2003);
- 1993 surficial sediment survey (Bedard and Petro 1995); and,
- 1979 surficial sediment survey (results presented in Anderson 1986).

Additionally, Milani and Grapentine (2005, In Prep.) examined sediment toxicity and biomagnification potential in studies conducted in the area in 2002 and 2005. Mercury data (i.e., concentrations measured in sediments) and data regarding sediment toxicity and biomagnification potential (Milani and Grapentine 2005, In Prep.) were compiled in NSC and Quester Tangent (2006).

Following completion of the most recent sediment survey conducted by NSC and Quester Tangent (2006), the Ontario MOE identified the need to generate estimates of sediment areas and volumes associated with:

- toxicity (Scenario 1);
- mercury biomagnification potential (Scenario 2);
- toxicity and biomagnification potential (Scenario 3); and,
- mercury concentrations above the Provincial Sediment Quality Guideline Severe Effect Level (PSQG SEL, Scenario 4).

This report presents the results of sediment area and volume estimates generated for the above scenarios. The information used to generate the estimates consisted of the results of recent sediment surveys conducted in the Study Area (i.e., Milani and Grapentine 2005, In Prep., NSC and Quester Tangent 2006). The following provides a brief description of the approach and methods employed for generating these estimates as well as a brief presentation of the results. Details regarding the raw data used to generate these estimates, as well as descriptions of the methods of data collection, can be found in Milani and Grapentine (2005, In Prep.) and NSC and Quester Tangent (2006).

2.0 APPROACH AND METHODS

2.1 STUDY AREA

The Thunder Bay AOC runs for approximately 28 km along the shoreline of Lake Superior, extending out to a maximum of 9 km offshore from the City of Thunder Bay (Figure 1). The Thunder Bay Harbour area of interest in this study is restricted to the area adjacent to the Cascades operation and is contained within the breakwall. This area represents the spatial extent of recent studies that formed the basis for deriving estimates of sediment areas and volumes presented herein.

2.2 DATA SOURCES

Concentrations of mercury measured in surficial sediments in 2002 (Milani and Grapentine 2005), summer 2005 (Milani and Grapentine In Prep.), and October 2005 (NSC and Quester Tangent 2006) were used for generating estimates of sediment areas and volumes. Sites where mercury concentrations exceeded the PSQG SEL of 2 µg/g d.w. (surficial sediments) were used to generate area and volume estimates. Where two values were available for a given site (i.e., data generated at a similar location in two different studies), the 'worst-case-scenario' was employed for generating area and volume estimates. Specifically, in instances where one of the two mercury concentrations exceeded the PSQG SEL, the site was assumed to exceed the SEL for the purposes of this exercise. A summary of the mercury data used is presented in Table 1.

Surficial sediment toxicity and biomagnification potential data were derived from Milani and Grapentine (2005, In Prep.). Estimates were based on sites identified as "severely toxic" and those with "biomagnification potential". A summary of the toxicity and biomagnification potential data used in this exercise is presented in Table 1.

Volume estimates and the extent of pulp in the Study Area were calculated based on the information presented in NSC and Quester Tangent (2006).

2.3 INTERPOLATION AND AREA/VOLUME ESTIMATES

Area and volume estimates were derived using Thiessen polygons (also known as Voronai polygons), which were used to interpolate the categorical data based on the irregularly distributed sampling sites. The result of this spatial interpolation method is that once constructed, any point within a Thiessen polygon is closer to its known point then any other point in the sample, thus creating an area of influence for all of the known points in a sample population (Chrisman, 1997). For each of the 4 scenarios in this study, ArcGIS® ArcView was used to generate Thiessen polygons based on the irregular distribution of sample sites, and also the breakwater of Thunder Bay Harbour.

Areas and volumes were calculated for each of the four scenarios where the sample site was above a specified limit (i.e., Hg above the PSQG SEL, site deemed severely toxic, or site identified as potential for biomagnification, or both), denoted as 'Yes' or 'No' in the figures (e.g., mercury is either above the SEL [Yes] or below the SEL [No]). Area estimates are equal to the planar horizontal extent of each Theissen polygon. Volume estimates were derived using two approaches. In the nearshore zone where pulp has accumulated, it is known that thickness varied considerably (NSC and Quester Tangent 2006). Consequently, an interpolated pulp and pulp/silt thickness dataset from NSC and Quester Tangent (2006) was used to calculate the volume that falls within each of the Thiessen polygons. In the offshore zone, where silt and silt/sand predominated the bottom (i.e. past the extent of pulp), variation in the observed thickness was limited and no volume estimates from previous work were available. In this case, volume estimates were generated using sediment depths (i.e., depth of refusal) measured during sediment probing exercises conducted at each sampling site within each Theissen polygon (NSC and Quester Tangent 2006). This second method of estimating volume assumes that the thickness observed at the sampling site is the same throughout each polygon.

3.0 RESULTS

The results of the area and volume estimates generated for the four scenarios are presented in Table 3. The spatial distribution of each the four scenarios are reviewed below. The total Study Area represented in this analysis is 983,149 m^2.

3.1 SCENARIO 1 – SEVERELY TOXIC SITES

With one exception (site P12), severely toxic sites are located within the area of pulp and pulp/silt accumulation relatively proximate to the Cascades outfall (Figure 2). The area and volume for the zone within the pulp and pulp/silt accumulation (i.e. P1, P3, P6, P7, S05-01, S05-11) were estimated to be 184,177 m^2 and 317,234 m^3, respectively. Unlike all other shallow water areas, the area surrounding site S05-03 is not classified as severely toxic but is found within the area of pulp and pulp/silt accumulation where most other toxic sites were observed. The area and volume associated with site P12 were estimated to be 25,133 m^2 and 10, 053 m^3, respectively.

The area and volume for the severely toxic sites for the entire Study Area were estimated to be approximately 209,310 m^2 and 327,287 m^3.

3.2 SCENARIO 2 – POTENTIAL BIOMAGNIFICATION SITES

Sites identified as exhibiting "potential biomagnification" are distributed in three areas that range across the Study Area (Figure 3). Within the extent of the pulp zone, sites P6, P7, and S05-11 are potential biomagnification sites, and represent a total area of 80,467 m^2 and a volume of 109,151 m^3.

In the offshore area beyond the extent of pulp, the potential biomagnification sites are found in two groups. Along the western extent of the Study Area, sites P23, P22, S05-08, S05-07, and P12 are identified as potential biomagnification sites. The total area and volume associated with these sites were estimated to be 157,531 m^2 and 115, 972 m^3, respectively.

In addition, site S05-14, which is located about half-way between the Cascades outfall and the western extent of the Study Area, has also been identified with the potential for biomagnification. The total area and volume associated with this site were estimated to be 34,624 m^2 and 12,119 m^3.

Overall, the total area and volume of sediments associated with potential biomagnification sites for the entire Study Area were estimated to be 272,622 m^2 and 237,242 m^3.

3.3 SCENARIO 3 – SEVERELY TOXIC AND POTENTIAL BIOMAGNIFICATION SITES

Sites identified as both severely toxic and with a potential for biomagnification are found in three areas and are represented by four sampling sites (Figure 4). Within the zone of pulp accumulation, sites P6, P7, and S05-11 are severely toxic and also have potential for bioaccumulation. The total area and volume for these areas were estimated to be 80,467 m^2 and 109,151 m^3. When combined with the zone surrounding site P12, the only site in the offshore zone also exhibiting severe toxicity and biomagnification potential, the total area and volume of sediments associated with sites identified as severely toxic and with the potential for biomagnification for the complete Study Area were estimated to be 105,600 m^2 and 119,204 m^3.

3.4 SCENARIO 4 – SITES ABOVE MERCURY SEVERE EFFECT LEVEL (SEL)

A single zone contains all sites where the concentration of mercury exceeds the PSQG SEL in surficial sediments (Figure 5); this zone appears to correspond roughly with the zone of pulp accumulation. Only two sites are located in the offshore zone (P10, S04), but are located relatively near the boundary of the extent of pulp. Site P2 is found within the zone of pulp accumulation but does not exceed SEL. The total area and volume of the zones represented by sites that exceed the SEL are 279,548 m^2 and 367,998 m^3.

4.0 LITERATURE CITED

Anderson, J. 1986. Nearshore water quality at Thunder Bay, Lake Superior, 1983. Great Lakes Section, Water Resources Branch, Ontario Ministry of Environment. November, 1986. 55 pp.

Bedard, D. and S. Petro. 1995 Laboratory sediment bioassay report on Thunder Bay sediments at the Abitibi-Price Provincial Papers and Fort William Mills 1993. A report prepared for D. Pugh, Northwestern Region, Thunder Bay Regional Office by the Standards Development Branch, Ontario Ministry of Environment and Energy, Etobicoke, ON.

British Columbia Ministry of Environment, Lands and Parks (BCMELP). 1997. Guidelines for interpreting water quality data. Version 1.0. British Columbia Ministry of Environment, Lands and Parks.

Chrisman, C. 1997. Exploring Geographic Information Systems. New York: John Wiley & Sons.

Fletcher, R. In prep. Ontario Ministry of the Environment, 125 Resources Road, Etobicoke, Ontario, M9P 3V6.

Jaagumagi, R. 2001. Thunder Bay waterfront storm sewer discharge survey water and sediment study. October, 2000. Prepared for the Northern Region, Ministry of Environment by Environmental Monitoring and Reporting Branch, May, 2001.

Milani, D. and L.C. Grapentine. 2005. Biological effects of mercury-contaminated sediment in northern Thunder Bay, Lake Superior. NWRI No. 05-326

Milani, D. and L.C. Grapentine. In Prep. Biological assessment of sediment quality in Thunder Bay North Harbour, 2005. Aquatic Ecosystems Impacts Research Branch, National Water Research Institute, Burlington, ON. (In Prep.)

North/South Consultants Inc. (NSC) and Quester Tangent Corp. 2006. Report on the collection, handling, and analysis results of sediment samples from the Thunder Bay north harbour, October 2005. A report prepared for the Ontario Ministry of the Environment.

Persaud, D., R. Jaagumagi, and A. Hayton. 1992. Guidelines for the protection and management of aquatic sediment quality in Ontario. ISBN 0-7729-9248-7. Ontario Ministry of the Environment, Water Resources Branch, Toronto, ON.

Richman, L.A. 2004. Great Lakes reconnaissance survey. Water and sediment quality monitoring survey harbours and embayments Lake Superior and the Spanish River. Water Monitoring Section, Ontario Ministry of Environment. January 6, 2004.

Stantec Consulting Ltd. (Stantec). 2003. Mercury investigation in Thunder Bay Harbour sediment. A report prepared for Cascades Fine Paper Group (Thunder Bay, ON) and Abitibi-Consolidated Inc. (Montreal, QB) by Stantec Consulting Ltd., Brampton, ON. Project No. 631 20872.3, January 2003.

Thunder Bay RAP Team. 2004. Thunder Bay Remedial Action Plan Stage 2: Remedial strategies for ecosystem restoration. May 2004.

Thunder Bay RAP Team. 1991. Thunder Bay Area of Concern Remedial Action Plan Stage 1: Environmental conditions and problem definition. September 1991, ISBN 0-7729-9032-8. 109 pp.

TABLES AND FIGURES

Table 1. Summary of surficial sediment mercury concentration, toxicity, and potential biomagnification data for sites analysed by NSC (2006) and Milani and Grapentine (2005, In Prep.) in the Study Area. Mercury data indicated in red exceed the PSQG SEL.

Sampling Sites			Total Mercury (ug/g d.w.)			Toxicity [1,2]	Potential Biomagnification [1]
Milani and Grapentine (2005): 2002 data	Milani and Grapentine (In Prep): 2005 data	NSC and QTC (2006): 2005 data	Milani and Grapentine (2005): 2002 data	Milani and Grapentine (In Prep): 2005 data	NSC and QTC (2006): 2005 data		
	-	1	-	-	4.14	No information	No information
-	S05-01	-	-	2.47	-	S	-
-	S05-02	2	-	1.36	2.00	-	-
-	S05-03	3	-	3.03	5.40	-	-
-	S05-04	4	-	3.72	1.07	-	-
-	S05-05	5	-	0.59	0.51	-	-
-	S05-06	6	-	0.54	0.61	-	-
-	S05-07	7	-	0.19	0.22	-	x
-	S05-08	8	-	0.16	0.23	-	x
	-	9	-	-	0.09	No information	No information
-	S05-10	10	-	0.04	0.073	-	-
-	S05-11	11	-	4.98	5.96	S	x
-	S05-12	12	-	0.88	1.12	-	-
-	S05-13	13	-	0.81	0.86	P	-
-	S05-14	14	-	0.10	0.10	-	x
-	S05-15	15	-	0.33	0.37	-	-
-	S05-16	-	-	0.44	-	T	-
P1	-	16	3.58	-	5.12	S	-
P2	-	-	0.711	-	-	-	-
P3	-	17	1.01	-	3.06	S	-
P4	-	-	1.54	-	-	-	-
P5	-	-	0.882	-	-	-	-
P6	-	18	39.7	-	8.23	S	x
P7	-	19	34.3	-	11.4	S	x
P8	-	-	0.936	-	-	-	-
P9	-	-	0.687	-	-	-	-
P10	-	-	2.03	-	-	-	-
P11	-	-	1.22	-	-	-	-
P12	-	20	0.626	-	0.45	S	x
P13	-	21	0.417	-	0.32	-	-
P16	-	-	0.12	-	-	-	-
P17	-	22	0.459	-	0.38	-	-
P18	-	-	0.32	-	-	-	-
P22	-	23	0.169	-	1.79	-	x
P23	-	24	0.120	-	0.33	-	x

[1] Milani and Grapentine (2005, In Prep.)
[2] S = severely toxic; T = toxic; P = potentially toxic; - = not toxic; No information = not assessed.

Table 2. Summary of surficial sediment mercury, toxicity, and potential biomagnification data by site used for estimates of sediment areas and volumes.

Sampling Sites			Metadata for Sediment Area and Volume Estimates			
Milani and Grapentine (2005): 2002 data	Milani and Grapentine (In Prep): 2005 data	NSC and QTC (2006): 2005 data	Hg > PSQG SEL	Toxicity	Potential Biomagnification	Potential Biomagnification and Toxicity
	-	1	Y	No information	No information	No information
-	S05-01	-	Y	Y	N	N
-	S05-02	2	Y	N	N	N
-	S05-03	3	Y	N	N	N
-	S05-04	4	Y	N	N	N
-	S05-05	5	N	N	N	N
-	S05-06	6	N	N	N	N
-	S05-07	7	N	N	Y	N
-	S05-08	8	N	N	Y	N
	-	9	N	No information	No information	No information
-	S05-10	10	N	N	N	N
-	S05-11	11	Y	Y	Y	Y
-	S05-12	12	N	N	N	N
-	S05-13	13	N	N	N	N
-	S05-14	14	N	N	Y	N
-	S05-15	15	N	N	N	N
-	S05-16	-	N	N	N	N
P1	-	16	Y	Y	N	N
P2	-	-	N	N	N	N
P3	-	17	Y	Y	N	N
P4	-	-	N	N	N	N
P5	-	-	N	N	N	N
P6	-	18	Y	Y	Y	Y
P7	-	19	Y	Y	Y	Y
P8	-	-	N	N	N	N
P9	-	-	N	N	N	N
P10	-	-	Y	N	N	N
P11	-	-	N	N	N	N
P12	-	20	N	Y	Y	Y
P13	-	21	N	N	N	N
P16	-	-	N	N	N	N
P17	-	22	N	N	N	N
P18	-	-	N	N	N	N
P22	-	23	N	N	Y	N
P23	-	24	N	N	Y	N

Table 3. Sediment area and volume estimates for four scenarios. Scenarios are based on site characteristics as follows: Scenario 1: sites severely toxic; Scenario 2: sites with potential for biomagnification; Scenario 3: sites that are both severely toxic and have potential for biomagnification; and, Scenario 4: sites with mercury above the PSQG SEL of 2 µg/g.

Scenario	Site	Area (m^2)	Volume (m^3)	Material
1	P12	25133	10053	Silt/Sand
1	P7	41036	52695	Combined*
1	P3	52649	106210	Pulp and Pulp/Silt
1	S05-11	17597	10494	Pulp and Pulp/Silt
1	S05-01	32174	70137	Pulp and Pulp/Silt
1	P6	21833	45963	Pulp and Pulp/Silt
1	P1	18888	31735	Pulp and Pulp/Silt
Total		209310	327287	
2	S05-07	39646	31717	Silt/Sand
2	S05-08	23257	18606	Silt/Sand
2	P12	25133	10053	Silt/Sand
2	P22	34496	27597	Silt/Sand
2	P23	34999	27999	Silt/Sand
2	S05-14	34624	12119	Silt/Sand
2	P7	41036	52695	Combined*
2	S05-11	17597	10494	Pulp and Pulp/Silt
2	P6	21833	45963	Pulp and Pulp/Silt
Total		272622	237242	
3	P12	25133	10053	Silt/Sand
3	P7	41036	52695	Combined*
3	S05-11	17597	10494	Pulp and Pulp/Silt
3	P6	21833	45963	Pulp and Pulp/Silt
Total		105600	119204	
4	P3	45933	90282	Pulp and Pulp/Silt
4	S05-11	16604	9622	Pulp and Pulp/Silt
4	NSC1	29527	63190	Pulp and Pulp/Silt
4	S05-01	13461	26107	Pulp and Pulp/Silt
4	P6	21833	45963	Pulp and Pulp/Silt
4	P10	22630	13578	Silt/Sand
4	S05-03	16353	6903	Pulp and Pulp/Silt
4	P1	18888	31735	Pulp and Pulp/Silt
4	S05-04	29423	16214	Combined*
4	P7	41036	52695	Combined*
4	S05-02	23770	11709	Combined*
Total		279458	367998	

* Volume calculated from pulp thickness surface and Silt/Sand assumed constant thickness

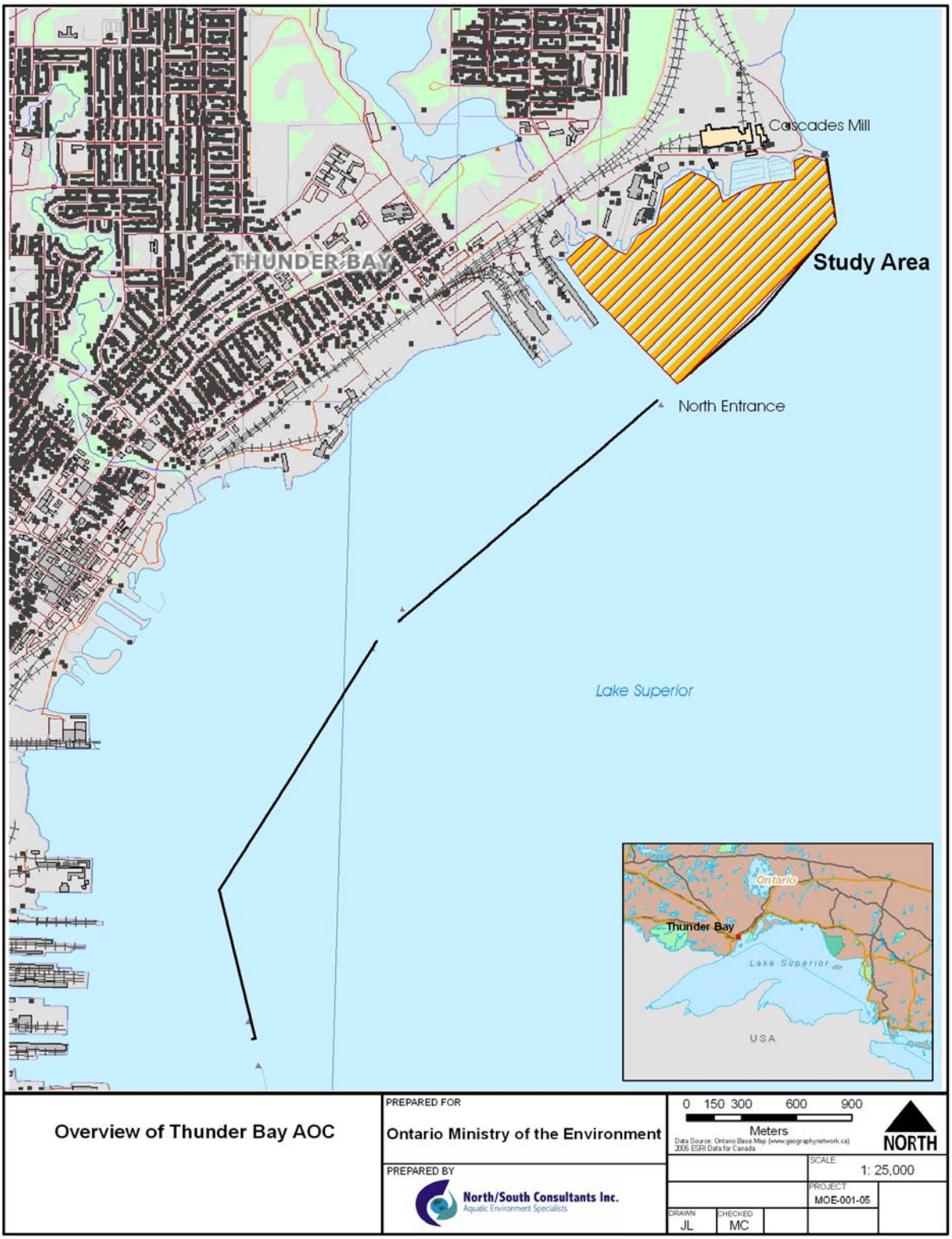

Figure 1. Thunder Bay Area of Concern and the Study Area.

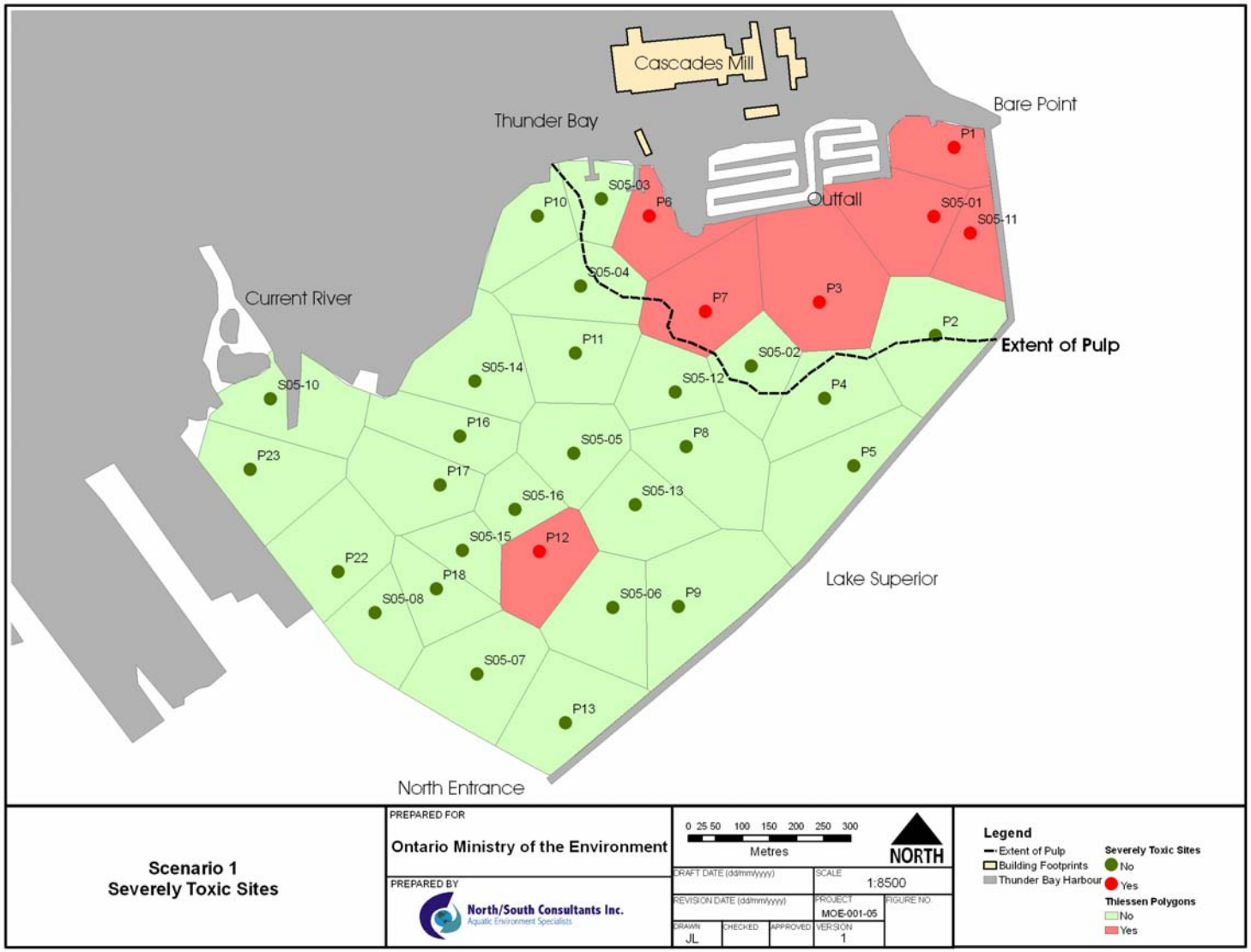

Figure 2. Scenario 1 showing areas surrounding sites identified as severely toxic.

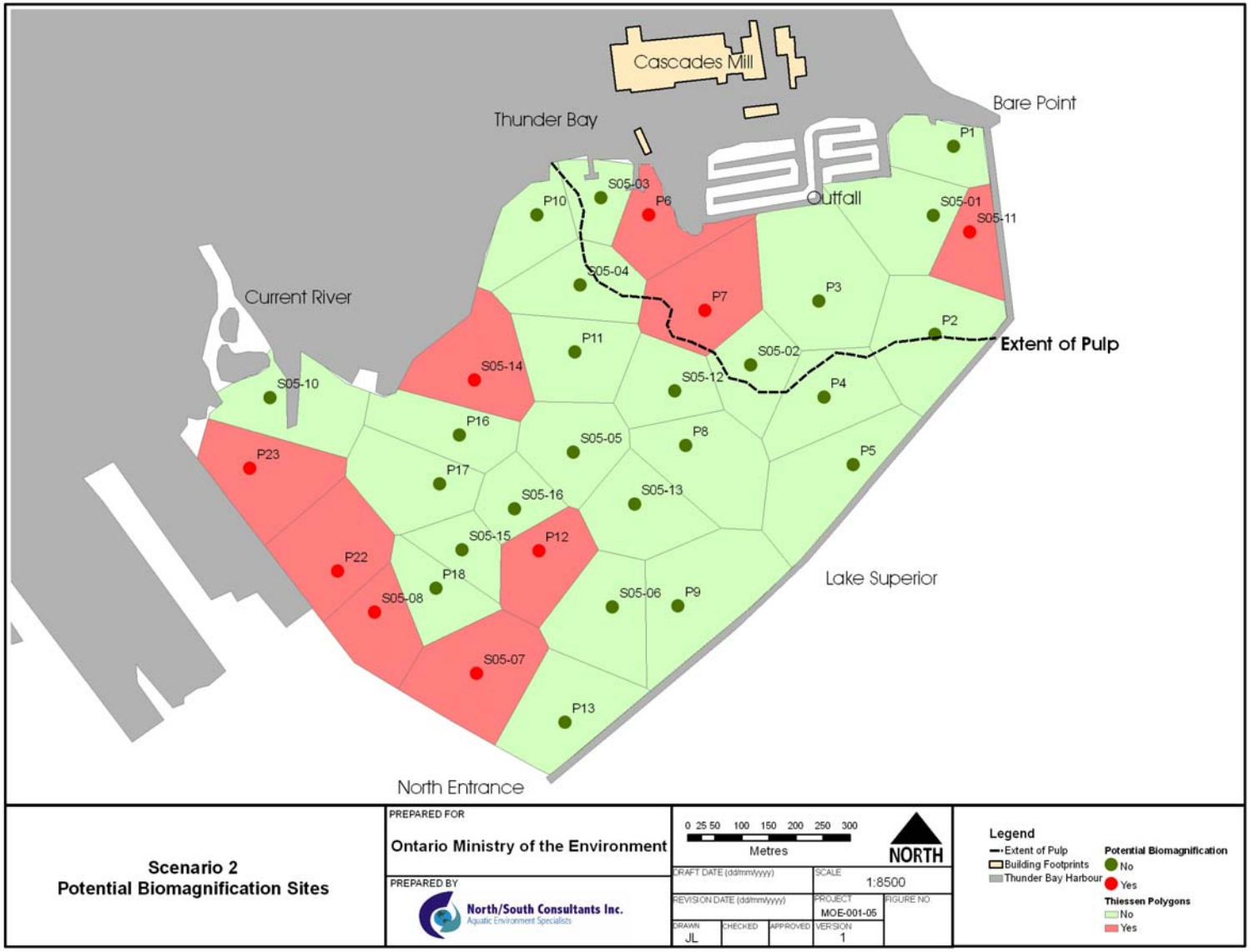

Figure 3. Scenario 2 showing areas surrounding sites with potential for mercury biomagnification.

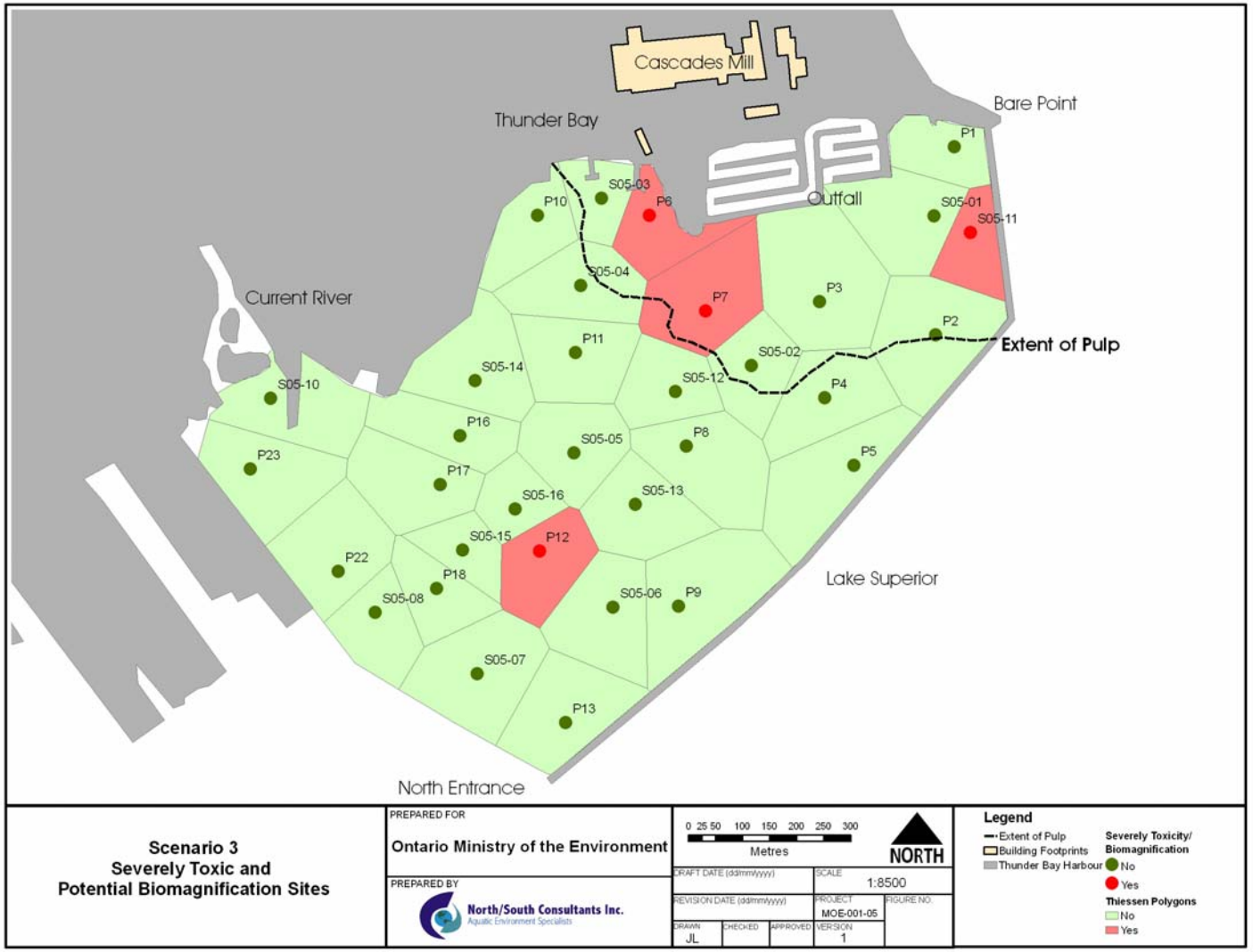

Figure 4. Scenario 3 showing areas surrounding sites that were identified as both severely toxic and with a potential for mercury biomagnification.

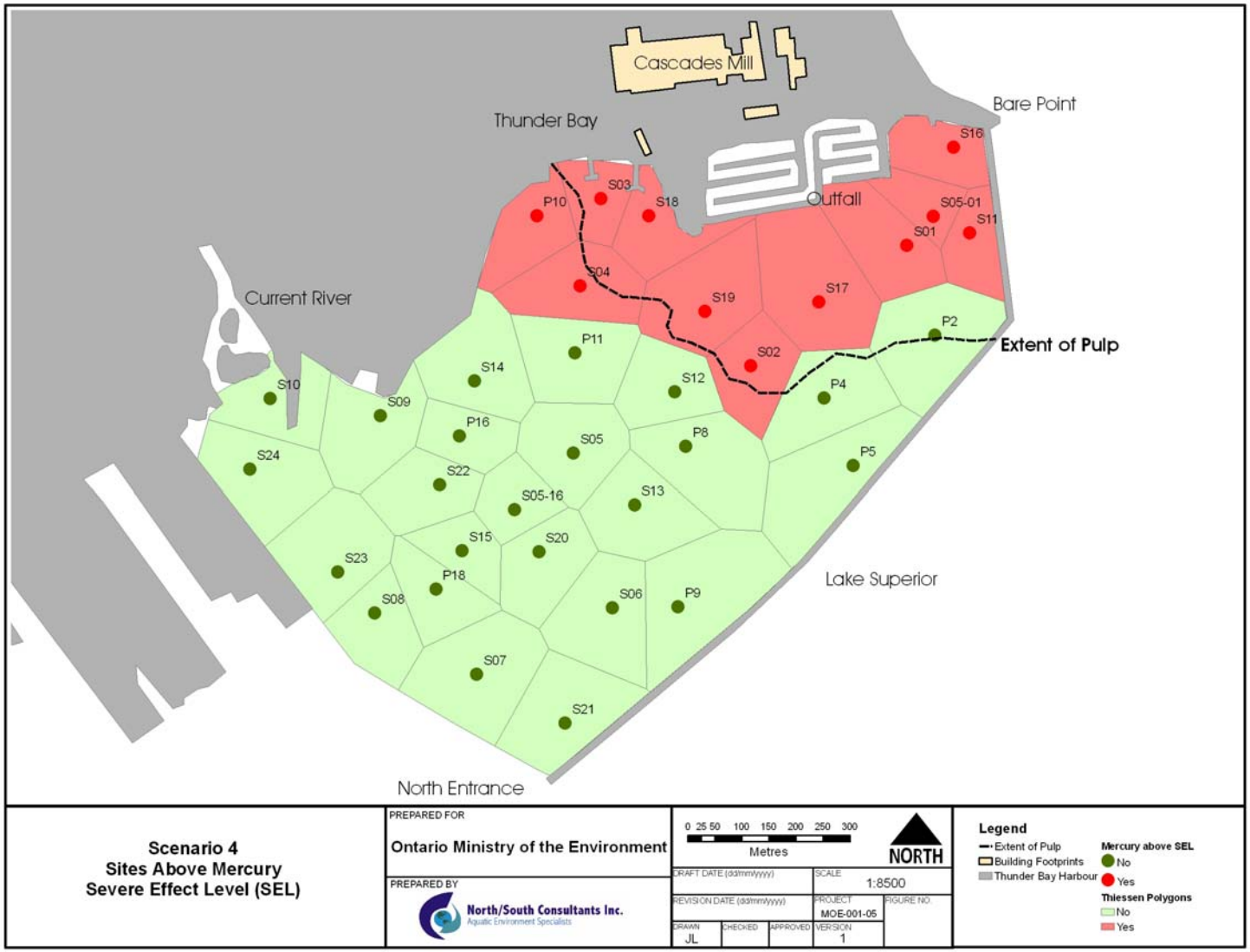

Figure 5. Scenario 4 showing areas surrounding sites where mercury concentrations exceed the provincial sediment quality guideline Severe Effect Level (SEL) of 2µg/g.